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Phase-Difference Processing Incorporating Time-Alignment and Time-Compression Techniques

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This report describes a system for measuring the instantaneous phase difference between two signals as a function of time. This system allows the user to apply various time-difference and doppler corrections to the signals in order to obtain minimum (in the least-squares sense) phase difference between the signals.

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PHASE-DIFFERENCE PROCESSING INCORPORATING
TIME-ALIGNMENT AND TIME-COMPRESSION TECHNIQUES

INTRODUCTION

Coherent processing has proven to be a viable technique in the study of undersea acoustic signals. To be effective, such processing requires the phase coherence between the received signals to be high. That is, the minimum phase difference between the two signals (after corrections for differences in transit times and doppler) must be small in the least-squares sense. Moreover the time-difference and doppler corrections required to achieve the minimum phase difference provide estimates of these parameters for localization and dynamics determination.

This report will examine the problem of correcting for time alignment and time scale-factor between two signals in the measurement of phase difference and describe in general terms a system for implementing these functions.

SYSTEM DESCRIPTION

The basic technique for measuring the instantaneous phase difference between two signals is illustrated in Fig. 1. The two bandlimited signals are processed through delay networks in order to align the two signals in time register, after which one of the two signals is processed through a time compressor (or expander) to correct for the doppler difference between the two channels. The signals are then fed to an axis-crossover comparator (phase meter) and a duel-trace oscilloscope. The phase difference between the two signals is recorded as a function of time on a Brush stylus recorder.
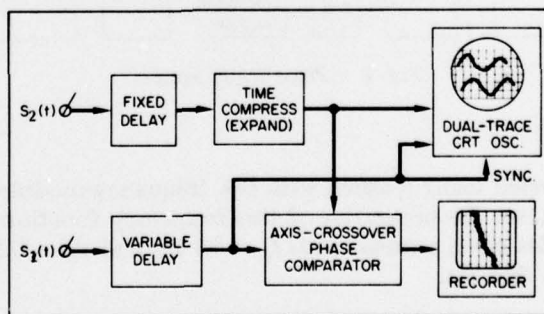

Fig. 1 — Phase-measurement technique

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Digital System

The process was implemented in two steps. In the first step of the process, time delays and time compressions (or expansions) were introduced to the data channels by the use of a PDP-11/40 minicomputer. Each of the digital signals was stored in a contiguous file on the system disk, which allowed the data streams to be accessed by sample number. The time delay for each of the signals is obtained by specifying the starting sample number for each channel. The time alignment between the two signals is varied by changing the starting sample number for the first signal relative to the second. Time is compressed (or expanded) by periodically skipping (or duplicating) samples from the second channel. The new data streams are multiplexed into a single data stream and written onto magnetic tape for processing by the phase meter. A more detailed explanation of the software program to accomplish this first step is given in Appendix A.

Axis-Crossover Phase Meter

In the second step of the process the magnetic tape that is generated is used as the signal input for the system shown in Fig. 2. Each record on the magnetic tape is read into one of two buffers. To maintain a continuous flow of data through the system, one buffer is being filled while the other is being read by the demultiplexer. The two demultiplexed data channels are digital-to-analog converted and low-pass filtered. Each channel is then fed to the phase meter. At each positive axis-crossover of the channel 1 signal, a counter in the phase meter is reset, and at each positive axis-crossover of the channel 2 signal the contents of the counter is converted to a voltage which is fed to the strip-chart recorder. (Further details on the axis-crossover phase meter are given in Ref. 1.)
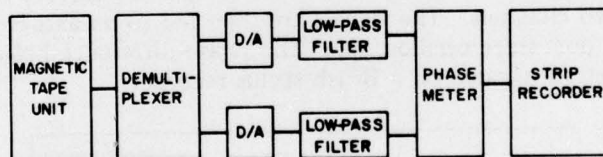

Fig. 2 — Phase-meter system

SYSTEM OPERATION

The system was tested using a signal with the frequency-modulation pattern illustrated in Fig. 3. (More details on the properties of this frequency function are reported in Ref. 2). In the examples given a signal with f_c = 33 Hz and Δf = 0.2 Hz were used. The signals were sampled at 264 Hz.

Time-Register Alignment

The first area of study was to determine the effect of time register (or time alignment) on the phase-difference pattern of identical signals. Figure 4 illustrates the phase-difference pattern for offsets of 0, 1, 2, 4, and 8 seconds. The 45-degree offset from the center of each plot is the result of the clocking from the demultiplexer. Each sample from channel
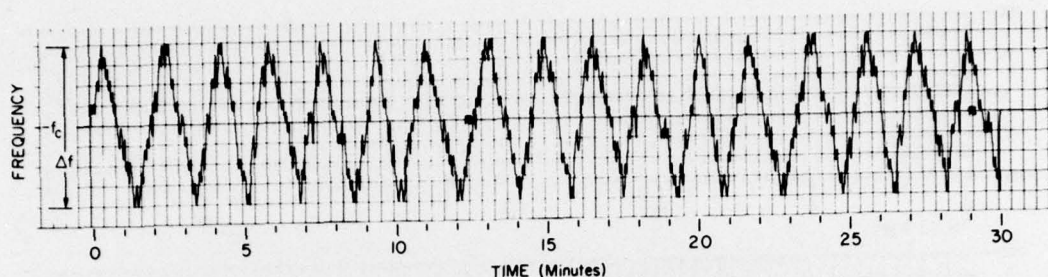
Fig. 3 — Source frequency function

2 is displaced 1/2 sample interval (1/8 wave period) after the corresponding sample for channel 1. In this example the phase-difference patterns approximate triangular wave forms, with peak-to-peak excursions directly proportional to the time-register difference.

Doppler Corrections

The system was also used to examine the effect of both time register and doppler alignment on a motional-source signal received at two widely spaced sensors. Since the locations of the source and sensors were known, it was easy to approximately time-align the signals. After the initial time alignment the phase-difference pattern appears as shown in Fig. 5a. The continuous phase migration (360-degree sawtooth wave) is a result of the doppler difference between the two received signals. Over the time interval of 30 minutes (475,200 samples) a cumulative phase difference of about 37-1/4 full periods (298 samples) is noted. To correct for doppler, it is thus necessary to drop a sample every 1595 samples from the second signal. The effect of this correction is shown in Fig. 5b. There is now no net phase movement of the phase difference over the 30-minute interval, but an irregular waveform similar to that shown in Fig. 4 may be noted. This suggests that some time-register difference still exists between the two signals. Figure 5c illustrates the final phase difference between the two signals after they have been properly time aligned. This final alignment indicates that the time difference between channel 2 and channel 1 was 1/2 second smaller than expected and that a doppler compression of 0.000627 (or 0.02069 Hz) existed between the two signals.

The high-frequency (45-degree-sawtooth) component of the phase-difference pattern seen in Figs. 5b and 5c is a result of the discrete manner of correcting for doppler difference. (The spikes in the Fig. 5 phase-difference plots are caused by tape dropouts during the reading of the magnetic tape and should be ignored.)

CONCLUSIONS

The system described in this report provides a simple and convenient method for measuring the instantaneous phase difference between two signals as a function of both time-register and time-scale-factor (doppler) difference. By examining the phase-difference plots, one can determine the time-register and doppler difference required for minimum phase
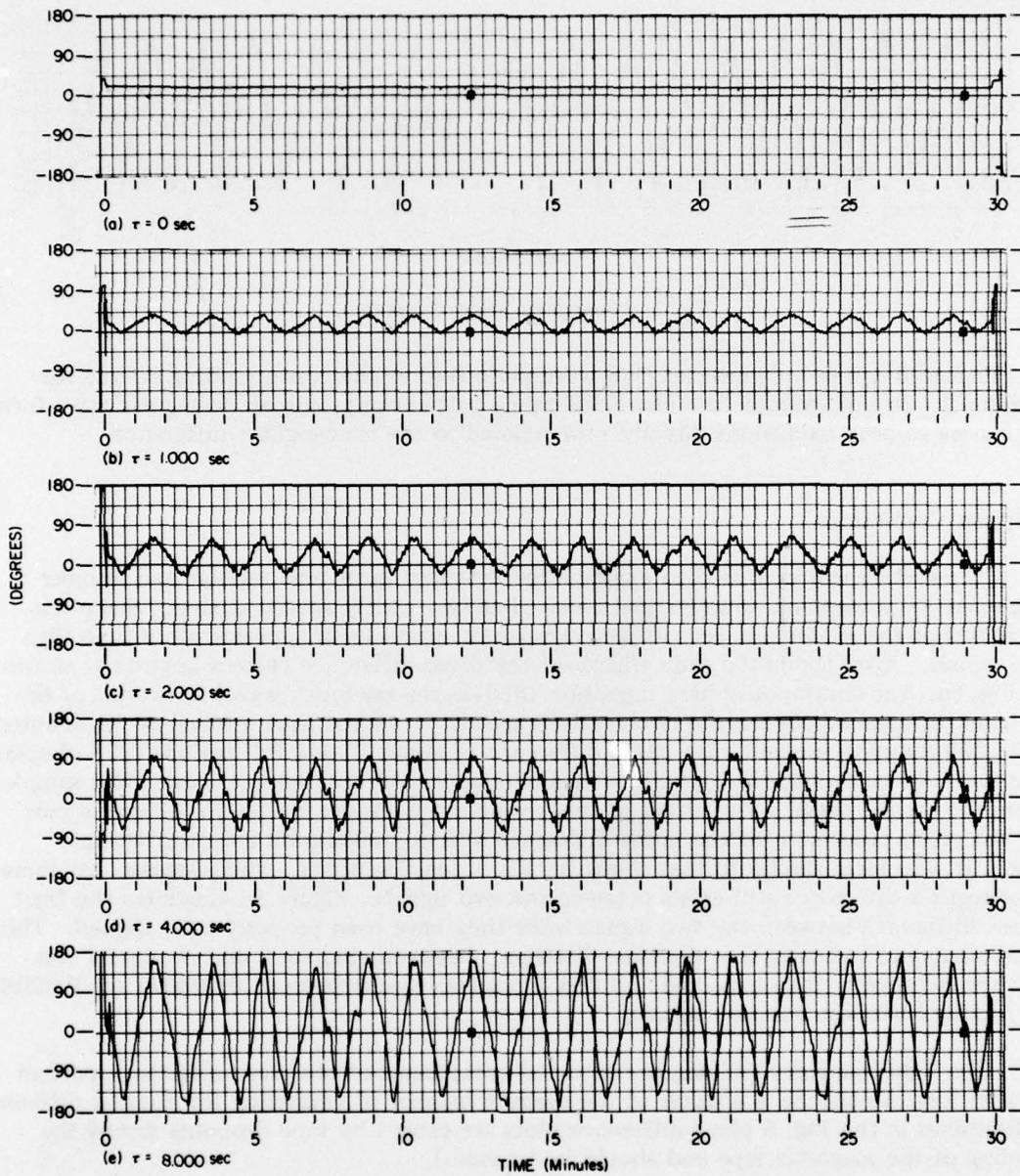
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Fig. 4 — Phase-difference plots of the signal versus itself
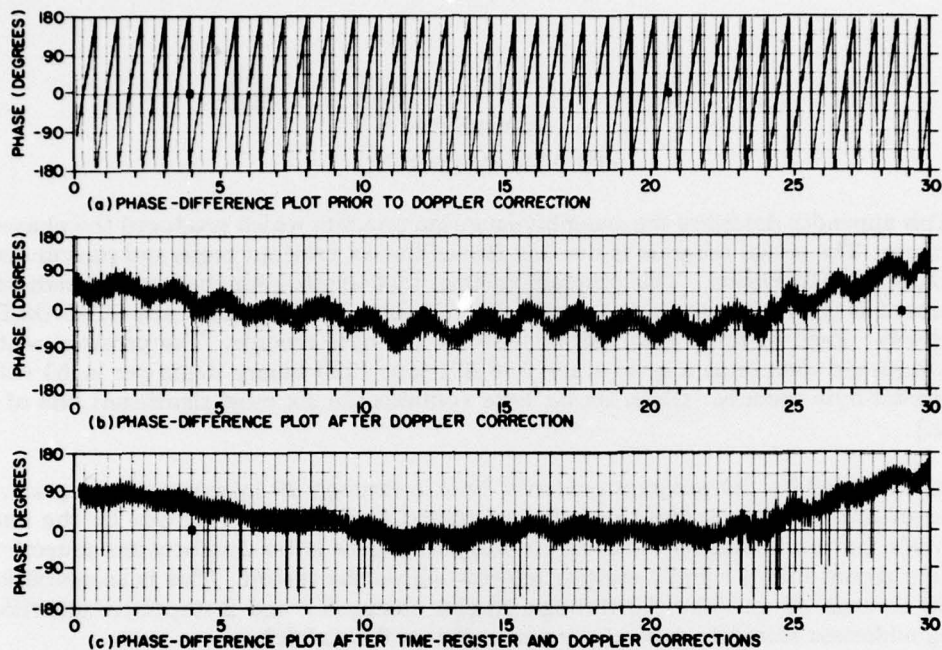
Fig. 5 — Phase-difference patterns of the signal received at separate sensors

difference. In so doing, estimates of the time-register and doppler shift are provided, and an estimate of the maximum phase correlation between the signal channels may readily be derived.

ACKNOWLEDGMENTS

REFERENCES

1. G. G. Nacht and H. L. Peterson, "A Hybrid Cumulative Phase Difference Meter," Report of NRL Progress, Feb. 1966, pp. 37-38.
2. A.A. Gerlach, "Random Frequency Function Generation," NRL Report 7697, Apr. 30, 1974.

Appendix A
PROGRAM LISTING

This appendix describes the assembly-language program which produced the phase-meter input tapes. The actual program is the first five of the six printout pages and runs under the DEC DOS/BATCH system. This program assumes that the data for the two channels have been stored as eight-bit bytes in the contiguous disk files STANO1.DAT and STANO2.DAT respectively. Each of these data files consists of 512-byte records. The program writes the multiplexed data onto a seven-track 556-BPI tape (556 binary digits per inch) with 2000 six-bit-byte records. (Each six-bit byte contains the six most significant bits of a sample.)

As indicated by the program contents, lines 1 through 29 initialize the program. The number of records in each input data file is entered first. This is followed by the number of samples that each data stream is to be delayed. These latter numbers are converted to a starting record number and a starting address within the record. This is accomplished by lines 39 through 43 and lines 53 through 58 (for channels 1 and 2 respectively), with the starting addresses stored in general-purpose registers R1 and R2.

Lines 60 and 61 of the program then examine bit 0 of the switch register to see if a doppler correction is to be made. If bit 0 is on (indicating a doppler correction), then the number of samples between address corrections is stored in DROP and DOPP, and the direction of the correction (retard or advance address by one) is stored in ANSWR.

The program now places the starting address of the output buffer in register R3 and sets the output-buffer counter register R4 to the size in words (one word is equivalent to two data samples) of the output buffer. The program then reads the first required data record for channels 1 and 2 into the buffers NPUT1 and NPUT2 respectively.

The program begins multiplexing the data channels into the output buffer. In line 84 a sample from channel 1 is moved from the channel 1 input buffer into the output buffer, and the two buffer pointers are incremented by 1. The process is repeated for channel 2 in line 85. The program then decrements the R4 counter by 1 and tests to see if the output buffer is full. If the buffer is full, the output buffer is written onto the magnetic tape and registers R3 (output-buffer pointer) and R4 (output-buffer counter) are reset.

Line 105 checks NOPOP to determine if a doppler correction is to be made. If so, the counter DROP is decremented by 1 and compared with zero. If DROP is zero, DROP is reset to DOPP and ANSWR is examined to determine whether a sample should be repeated or dropped. If a sample is to be repeated, the counter R2 is decremented by 1; and if a sample is to be dropped, R2 is incremented by 1 and the input buffer tested to determine if the channel-2 data have been exhausted. If the data have been exhausted, a new record is read into NPUT2.

This process continues until the program must access a record greater than the size of one of the input files (as specified by RECBL1 and RECBL2). Finally the most significant

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bit of the switch register is checked. If it is on, the program recycles to generate a new file of multiplexed data with a new time register and/or a new doppler correction. Otherwise control is returned to the DOS monitor.

An example of the entries to the program is shown in Fig. A1. (This program produced the data tape for the phase-difference plots shown in Fig. 5.) The underlined portions are the entries entered by the operator. In the example the data inputs are six-digit ASCII numbers, each less than the decimal number 65,536. In addition the entry indicating that samples were to be dropped from the second channel was a four-digit ASCII entry SUB2. (If samples were to have been added, the entry would have been ADD2.)

```
(all sense switches down)

$RU    DOPP12
LAST DATA RECORD FOR STATION 1                          001250
LAST DATA RECORD FOR STATION 2                          001250
NO. OF SAMPLES TO DROP FROM STATION-1 DATA              026400
NO. OF SAMPLES TO DROP FROM STATION-2 DATA              026400

(put sense switch 0 up)

NO. OF SAMPLES TO DROP FROM STATION-1 DATA              026400
NO. OF SAMPLES TO DROP FROM STATION-2 DATA              026400
NO. OF SAMPLES BETWEEN DOPPLER CORRECTIONS              001595
ADD OR SUB SAMPLES FROM CHANNEL 2?   SUB2

(put sense switch 15 up)

NO. OF SAMPLES TO DROP FROM STATION 1 DATA              026532
NO. OF SAMPLES TO DROP FROM STATION 2 DATA              026400
NO. OF SAMPLES BETWEEN DOPPLER CORRECTIONS              001595
ADD OR SUB SAMPLES FROM CHANNEL 2   SUB2
```

Fig. A1 — Example of a run of the multiplexing program

```
001          SW=177570
002 ; PROGRAM TO MULTIPLEX DATA
003          .TITLE   DOPPLR
004          .MCALL   .INIT,.RLSE,.WAIT,.OPEN,.CLOSE
005          .MCALL   .EXIT,.RECRD,.D2BIN,.TRAN,.RADPK
006          .GLOBL   OPUTI,OPUT,OPUTF,OPUTD
007 START:   .INIT    #DSKBL1
008          .INIT    #DSKBL2
009          .INIT    #KBBLK
010 ; OBTAIN NUMBER OF LAST RECORD IN FIRST FILE
011          .TRAN    #KBBLK,#TBLK1
012          .WAIT    #KBBLK
013          .TRAN    #KBBLK,#TRNBLK
014          .WAIT    #KBBLK
015          .D2BIN   #DECNO+1
016          MOV      (SP)+,RECNO1
017          DEC      RECNO1
018 ; OBTAIN NUMBER OF LAST RECORD IN SECOND FILE
019          .TRAN    #KBBLK,#TBLK2
020          .WAIT    #KBBLK
021          .TRAN    #KBBLK,#TRNBLK
022          .WAIT    #KBBLK
023          .D2BIN   #DECNO+1
024          MOV      (SP)+,RECNO2
025          DEC      RECNO2
026 ; INITIALIZE FILES
027 BEGIN:   .OPEN    #DSKBL1,#FILNM1
028          .OPEN    #DSKBL2,#FILNM2
029          JSR      R5,OPUTI
030 ; OBTAIN NUMBER OF SAMPLES TO SKIP FOR
031 ; CHANNEL 1
032          .TRAN    #KBBLK,#TBLK3
033          .WAIT    #KBBLK
034          .TRAN    #KBBLK,#TRNBLK
035          .WAIT    #KBBLK
036          .D2BIN   #DECNO+1
037 ; STARTING RECORD NUMBER FOR FIRST FILE INTO RECBL1
038 ; ADDRESS OF FIRST SAMPLE INTO R1
039          MOV      (SP)+,R1
040          CLR      R0
041          DIV      #512.,R0
042          ADD      R0,RECBL1+10
043          ADD      #NPUT1,R1
044 ; OBTAIN NUMBER OF SAMPLES TO SKIP FOR
045 ; CHANNEL 2
046          .TRAN    #KBBLK,#TBLK4
047          .WAIT    #KBBLK
048          .TRAN    #KBBLK,#TRNBLK
```

```
049            .WAIT   #KBBLK
050            .D2BIN  #DECNO+1
051  ; STARTING RECORD NUMBER FOR SECOND FILE IN RECBL2
052  ; ADDRESS OF FIRST SAMPLE INTO R3
053            MOV     (SP)+,R3
054            CLR     R2
055            DIV     #512.,R2
056            ADD     R2,RECBL2+10
057            MOV     R3,R2
058            ADD     #NPUT2,R2
059  ;  TEST TO SEE IF DOPPLR CORRECTIONS ARE TO BE MADE
060            MOV     @#SW,NODOP
061            BIC     #177776,NODOP
062            BEQ     INIT
063  ; OBTAIN NUMBER OF SAMPLES BETWWEN DOPPLER CORRECTIONS
064            .TRAN   #KBBLK,#TBLK5
065            .WAIT   #KBBLK
066            .TRAN   #KBBLK,#TRNBLK
067            .WAIT   #KBBLK
068            .D2BIN  #DECNO+1
069            MOV     (SP)+,DOPP
070            MOV     DOPP,DROP
071  ; DROP OR ADD SAMPLES FROM CHANNEL 2?
072            .TRAN   #KBBLK,#TBLK6
073            .WAIT   #KBBLK
074            .TRAN   #KBBLK,#TRNBL1
075            .WAIT   #KBBLK
076            .RADPK  #DECNO
077            MOV     (SP)+,ANSWR
078  ; INPUT DATA
079  INIT:     MOV     #OUT,R3
080            MOV     #1000.,R4
081            JSR     R5,RED1
082            JSR     R5,RED2
083  ; MULTIPLEX THE CHANNELS
084  LOOP:     MOVB    (R1)+,(R3)+       ;CHANNEL 1 SAMPLE INTO OUTPUT FILE
085            MOVB    (R2)+,(R3)+       ;CHANNEL 2 SAMPLE INTO OUTPUT FILE
086            DEC     R4
087            BNE     CONT              ;OUTPUT BUFFER FULL?
088            JSR     R5,OPUT           ;YES
089            BR      .+4
090            .WORD   OUT
091            MOV     #1000.,R4
092            MOV     #OUT,R3
093            JSR     R5,OPUTD
094            MOV     @#172520,R0
095            BIC     #175777,R0
096            BNE     DONE              ;ERROR IN WRITING?
097  CONT:     CMP     R1,#NPUT1+512.
098            BNE     NXT               ;LAST SAMPLE IN CHANNEL 1 BUFFER?
099            JSR     R5,RED1           ;YES
100            MOV     #NPUT1,R1
```

```
101 NXT:     CMP     R2,#NPUT2+512.
102          BNE     DOPPLR          ;LAST SAMPLE FOR CHANNEL 2 BUFFER?
103          JSR     R5,RED2         ;YES
104          MOV     #NPUT2,R2
105 DOPPLR:  TST     NODOP
106          BEQ     LOOP            ;DOPPLER CORRECTIONS USED?
107          DEC     DROP            ;YES
108          BNE     LOOP            ;MAKE A DOPPLER CORRECTION NOW?
109          MOV     DOPP,DROP       ;YES
110          CMP     ANSWR,ADD
111          BNE     TWO
112          DEC     R2              ;ADD A SAMPLE
113          JMP     LOOP
114 TWO:     INC     R2              ;DROP A SAMPLE
115          CMP     R2,#NPUT2+512.
116          BNE     LOOP            ;LAST SAMPLE FOR CHANNEL 2 BUFFER?
117          JSR     R5,RED2         ;YES
118          MOV     #NPUT2,R2
119          JMP     LOOP
120 ; READ DATA FOR CHANNEL 1
121 RED1:    CMP     RECBL1+10,RECNO1
122          BGT     DONE            ;CHANNEL 1 DATA EXHAUSTED?
123          .RECRD  #DSKBL1,#RECBL1 ;NO
124          .WAIT   #DSKBL1
125          MOV     RECBL1,R0
126          TSTB    RECBL1+1
127          BNE     ERROR
128          ADD     #1,RECBL1+10
129          RTS     R5
130 ; READ DATA FOR CHANNEL 2
131 RED2:    CMP     RECBL2+10,RECNO2
132          BGT     DONE            ;CHANNEL 2 DATA EXHAUSTED?
133          MOVB    NPUT2+512.,NPUT2-1    ;NO
134          .RECRD  #DSKBL2,#RECBL2
135          .WAIT   #DSKBL2
136          MOV     RECBL2,R0
137          TSTB    RECBL2+1
138          BNE     ERROR
139          ADD     #1,RECBL2+10
140          RTS     R5
141 ; PROCESSING DONE
141 ERROR:   .TRAN   #KBBLK,#TBLK
142          .WAIT   #KBBLK
143 DONE:    CLR     RECBL1+10
144          CLR     RECBL2+10
145          JSR     R5,OPUTF
146          .CLOSE  #DSKBL1
147          .CLOSE  #DSKBL2
148          TST     @#SW            ;TEST BIT 15 OF SWITCH REGISTER
149          BMI     FIN             ;IF ON DONE
```

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```
150            JMP      BEGIN      ;OTHERWISE GENERATE NEW MAG TAPE FILE
151 FIN:       .RLSE    #KBBLK
152            .RLSE    #DSKBL1
153            .RLSE    #DSKBL2
154            .EXIT
155 ; DISK LINK BLOCK
156            .WORD    0
157 DSKBL1:    .WORD    0
158            .RAD50   /DIS/
159            .WORD    1
160            .RAD50   /DK/
161            .WORD    0
162 DSKBL2:    .WORD    0
163            .RAD50   /DUS/
164            .WORD    1
165            .RAD50   /DK/
166 ; KEYBOARD LINK BLOCK
167            .WORD    0
168 KBBLK:     .WORD    0,0,1
169            .RAD50   /KB/
170 ; RECORD BLOCK FOR FIRST CHANNEL
171 RECBL1:    .WORD    4,NPUT1,512.,0,0
172 ; RECORD BLOCK FOR SECOND CHANNEL
173 RECBL2:    .WORD    4,NPUT2,512.,0,0
174 ; OUTPUT BLOCK FOR KEYBOARD
175 TBLK:      .WORD    0,MESG,4,2,0
176 TBLK1:     .WORD    0,MESG1,22.,2,0
177 TBLK2:     .WORD    0,MESG2,22.,2,0
178 TBLK3:     .WORD    0,MESG3,22.,2,0
179 TBLK4:     .WORD    0,MESG4,22.,2,0
180 TBLK5:     .WORD    0,MESG5,22.,2,0
181 TBLK6:     .WORD    0,MESG6,17.,2,0
182 MESG:      .ASCII   / ERROR/
183            .BYTE    15,12
184 MESG1:     .ASCII   /LAST DATA RECORD TO READ FOR STATION 1      /
185            .EVEN
186 MESG2:     .ASCII   /LAST DATA RECORD TO READ FOR STATION 2      /
187            .EVEN
188 MESG3:     .ASCII   /NO. OF SAMPLES TO DROP FROM STATION 1 DATA /
189            .EVEN
190 MESG4:     .ASCII   /NO. OF SAMPLES TO DROP FROM STATION 2 DATA /
191            .EVEN
192 MESG5:     .ASCII   /NO. OF SAMPLES BETWEEN DOPPLER CORRECTIONS /
193            .EVEN
194 MESG6:     .ASCII   /ADD OR SUB SAMPLES FROM CHANNEL 2? /
195            .EVEN
196 ADD:       .RAD50   /ADD/
197 ; TRAN BLOCK FOR KEYBOARD
198 TRNBLK:    .WORD    0,DECNO,4.,5,0
199 TRNBL1:    .WORD    0,DECNO,3,4,0
```

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```
200 ; FILENAME FOR FIRST CHANNEL
201           .WORD   0,1
202 FILNM1: .RAD50  /STAN01DAT/
203           .WORD   0,233
204 ; FILENAME FOR SECOND CHANNEL
205           .WORD   0,1
206 FILNM2: .RAD50  /STAN02DAT/
207           .WORD   0,233
208 ; STORAGE AREAS
209 ANSWR:  .WORD   0
210 DOPP:   .WORD   0
211 DROP:   .WORD   0
212 RECNO1: .WORD   0
213 RECNO2: .WORD   0
214 OUT:    .BLKW   1000.
215 DECNO:  .BLKW   4
216 NPUT1:  .BLKW   256.
217         .WORD   0
218 NPUT2:  .BLKW   256.
219 NODOP:  .WORD   0
220         .END    START
```

```
001
002 ; OPUTI - INITIALIZATION FOR OUTPUT
003 ; OPUT  - OUTPUTS A RECORD TO 7 TRACK MAG TAPE (556 BPI)
004 ; OPUTD - CHECKS TO SEE IF OUTPUT COMPLETED
005 ; OPUTF - CLOSES FILE
006         .TITLE  OUTPUT
007         .MCALL  .INIT,.TRAN,.WAIT,.RLSE,.SPEC
008 OPUTI:: .INIT   #MAGBLK
009         .SPEC   #MAGBLK,#SFBLK
010         RTS     R5
011 OPUT::  MOV     R1,-(SP)
012         MOV     R0,-(SP)
013         MOV     2(R5),TRNBLK+2
014         MOV     TRNBLK+2,R1
015         MOV     #2000.,R0
016 LOOP:   ASRB    (R1)
017         ASRB    (R1)+
018         SOB     R0,LOOP
019         .TRAN   #MAGBLK,#TRNBLK
020         MOV     (SP)+,R0
021         MOV     (SP)+,R1
022         RTS     R5
023 OPUTD:: .WAIT   #MAGBLK
024         RTS     R5
025 OPUTF:: .SPEC   #MAGBLK,#SFBLK1
026         .RLSE   #MAGBLK
027         RTS     R5
028 SFBLK:  .BYTE   6,3
029         .WORD   0
030         .BYTE   0,1
031         .WORD   0
032 SFBLK1: .BYTE   2,3
033         .WORD   0,0,0
034         .WORD   0
035 MAGBLK: .WORD   0
036         .RAD50  /MAG/
037         .BYTE   1,1
038         .RAD50  /MT/
039 TRNBLK: .WORD   0,0,1000.,2,0
040         .END
```